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Palmyra *Rhodactis* Monitoring Project (PRMP)
Progress Report March 30th 2015

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Background

In 1991 a longliner vessel (*Hui Feng*) wrecked on the shallow western reef terrace of Palmyra Atoll National Wildlife Refuge (PANWR). In 2004 when the grounded vessel was first surveyed, low densities of the fleshy (non-calcifying) corallimorph *Rhodactis howesii* were observed (Work et al. 2008). By 2008 densities had exploded and *Rhodactis* is now one of the dominant benthic competitors surrounding the shipwreck area (Work et al. 2008) (Fig. 1). While the exact mechanism behind this corallimorph phase-shift is still unknown, it was hypothesized that iron leaching out of the vessel could be tipping the competitve balance in favor of the corallimorphs (Work et al. 2008). Excess iron levels in the oligotrophic central Pacific have since been linked to other phase-shifts on coral reefs including cyanobacterial and filamentous green algae (Wegley Kelly et al. 2012). PANWR represents a biodiversity hotspot in the central Pacific (Williams et al. 2008; Maragos and Williams 2011) and the reefs surrounding the Atoll system boast some of the highest cover of calcifying benthic organisms (Williams et al. 2013) and predatory fish biomass (Sandin et al. 2008) in the central Pacific Ocean. As such, any threats to reef health require management actions to reinstate reef resilience and promote persistance of reef-building (calcifying) organisms.

The US Fish and Wildlife Service (USFWS) had a requirement to survey and map the extent of the corallimorph, *Rhodactis howesii,* on the western terrace of PANWR prior to and following the removal of the *Hui Feng* shipwreck. The shipwreck was successfully removed in late 2013. The Palmyra *Rhodactis* Monitoring Project (PRMP) is a collaborative effort between the USFWS (Dr. Amanda Pollock) and Scripps Institution of Oceanography (SIO) (Dr. Gareth Williams) to quantify the effects of the shipwreck removal on coral reef benthic communities and their potential resilience following such management actions at the PANWR. Over the next several years the PANWR will be responsible for monitoring the effects of the shipwreck removal on the benthic and fish communities. The PRMP began in July 2013 and is currently scheduled to run until July 2016.
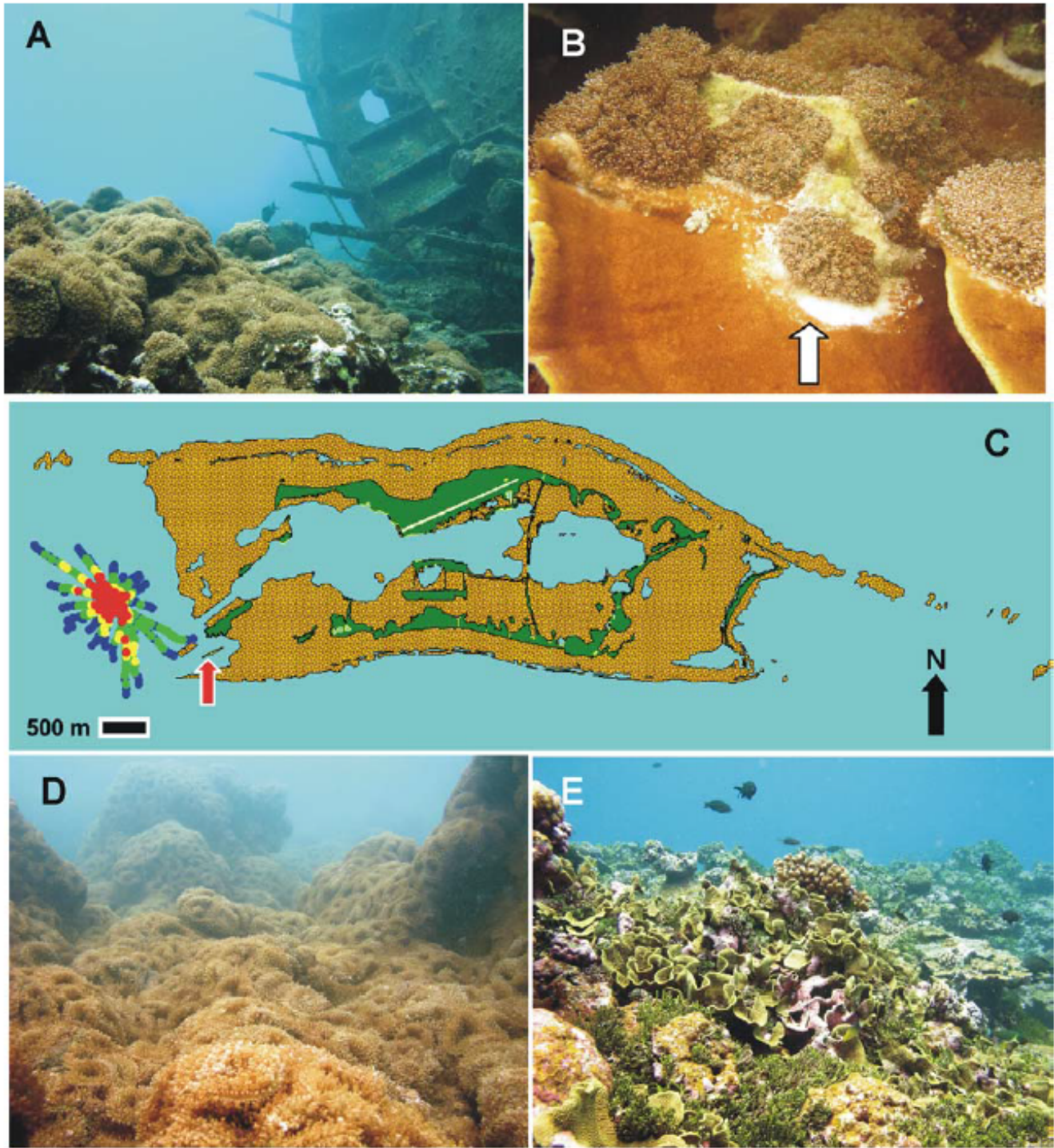
Figure 1. Invasion of the shallow western reef terrace at Palmyra Atoll by the corallimorph *Rhodactis howesii*. A) *Rhodactis* beds next to the shipwreck, B) *Rhodactis* actively killing hard coral, C) Density estimates of *Rhodactis* – the shipwreck was in the center of the red zone (>60% cover), D) 100% cover of *Rhodactis* in places, E) an unaffected portion of reef on the shallow terrace. Figure adapted from Work et al. (2008).

Project methods

Past monitoring at Palmyra has largely used the photo-quadrat method (Preskitt et al. 2004) to quantify benthic communities across reef habitats and depths (Williams et al. 2013). However, a disadvantage of this method is the inability to document large areas, to capture the dynamics of larger coral individuals that are greater than 0.6 – 1.0 m in diameter (standard quadrat size), and the time intensive nature of installing permanent demarcation in order to relocate the quadrat positions. Benthic photomosaics are a recent advancement allowing contonuous areas of the reef floor to be captured using digital imagery (Lirman et al. 2007; Gleason et al. 2010). At Palmyra, photomosaics have been used as part of a coral reef resilience project (the Reefs Tomorrow Initiative – RTI) to document benthic dynamics over time. The RTI project currently employs the use of 10 x 10 m plots. Due to the expansive nature of the *Rhodactis* infestation on Palmyra's reef terrace, however, as part of the PRMP we developed a novel camera system and methodology to document landscape-scale (100 x 100 m) plots.

Development of a semi-autonomous towed-camera system (TCS)

We designed and built a sub-surface towed-camera system (TCS) to map Palmyra's shallow (< 5m) benthic habitats to a reasonably high (sub-meter) resolution. The system was constructed from lightweight aluminum Speed-Rail® with a Delrin® coating and marine grade (316) stainless steel hardware. The TCS operates in a semi-autonomous fashion, with a tow line and pulley system linking the raft to a moving boat; a snorkeler traveling on the TCS was used to guide safe passage through very shallow areas. Two GoPro Hero3© camera arrays (black edition) were employed, with each array containing four cameras (Fig. 3). The TCS was positioned ~50 cm below the water's surface using a float system to prevent air bubbles entering the cameras' field of views and to provide increased stability in the event of surface chop. The clear waters of Palmyra's reefs allowed us to map to a depth of ~5 m while maintaining sufficient video quality to make post-hoc genus-level identifications of benthic organisms from the video frame grabs.

The TCS was towed at a speed of ~2km/hr behind a fiberglass boat (Carolina Skiff) powered by a 20 horsepower outboard engine. The optimal towing distance behind the boat was found to be ~8 m; this ensured adequate distance from bubbles created by the propeller and optimized independent maneuverability of the TCS. Importantly, the pulley system allowed the TCS to remain on a steady trajectory and thus ensure consecutive overlap between successive survey tracks, even as the boat maneuvered around potential hazards. Such overlap is of paramount importance to the success of the post-hoc image matching and mosaicing. The GoPro© cameras recorded high-definition video (1080p, 127° field of view, 48fps) with only one of the two arrays recording at any one time. This set-up provided approximately four hours of total survey time (using the Hero3© extended battery packs) without the need for replacing the arrays.

Mapping progress was monitored using nine temporary moorings demarking the corners, edge mid-points, and center of sequential 100 × 100 m plots. Coordinates were recorded for each mooring and care was taken to include them in the video swaths to aid with scaling the final mosaic image. The TCS was towed in a double lawnmower pattern across the entire 100 × 100 m plot, ensuring ~80 % spatial overlap between successive passes using a Garmin 76cx GPS unit fitted with an external antenna to increase accuracy. Once the plot was completed, six of the nine moorings were then moved to create an adjacent novel 100 × 100 m plot and the surveys repeated, with care taken to include portions of the previous plot in the new survey tracks. Tidal regimes at Palmyra allowed us to map approximately 5000 – 10,000 m^2 per day (defined as 4 – 6 hours of total survey time). From surveys during July 2013 and July 2014 a permanent monitoring area of approximately 35,000 m^2 has been identified for repeat surveying (Fig. 2).
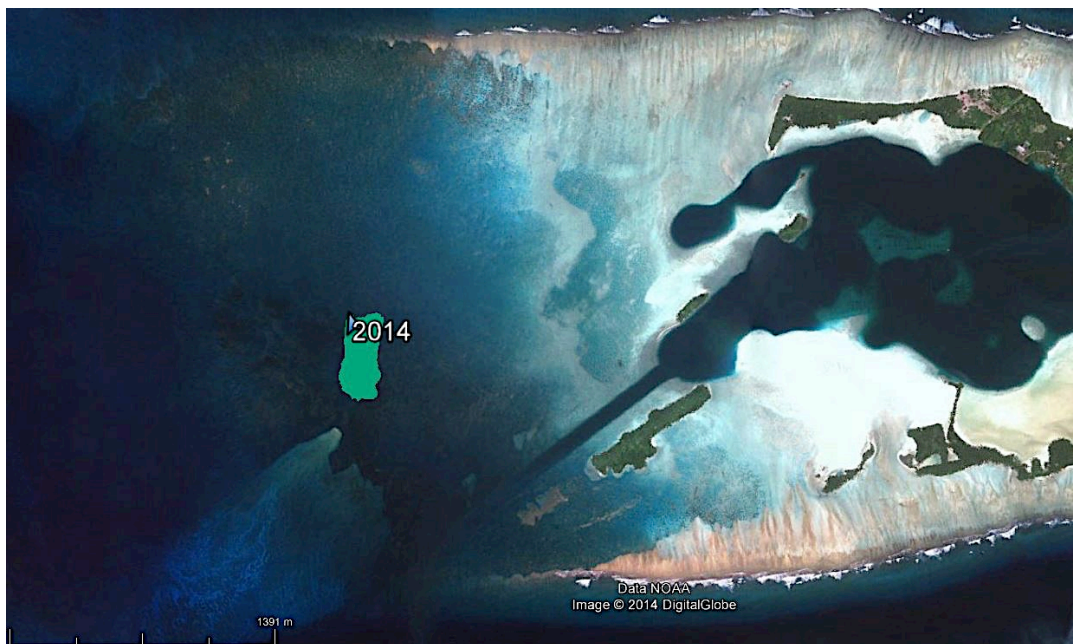

Figure 2. The PRMP longterm monitoring plot on Palmyra's shallow western reef terrace (green area). The area captures approximately 35,000 m^2 of reef as is the largest *in situ* coral reef monitoring plot in the world.

Surveys using the TCS were supplemented with a very high resolution (sub-centimeter) monitoring plot (200 m^2) established adjacent to the longliner vessel embedded within the larger PRMP monitoring plot. This plot was mapped using a customized dual-SLR camera system shooting digital stills. This plot was established in September 2012 and seubsequently surveyed in September 2013 and September 2014 for consistency. This plot will allow us to track very high-resolution changes, including the outcome of individual coral-*Rhodactis* battles for space.
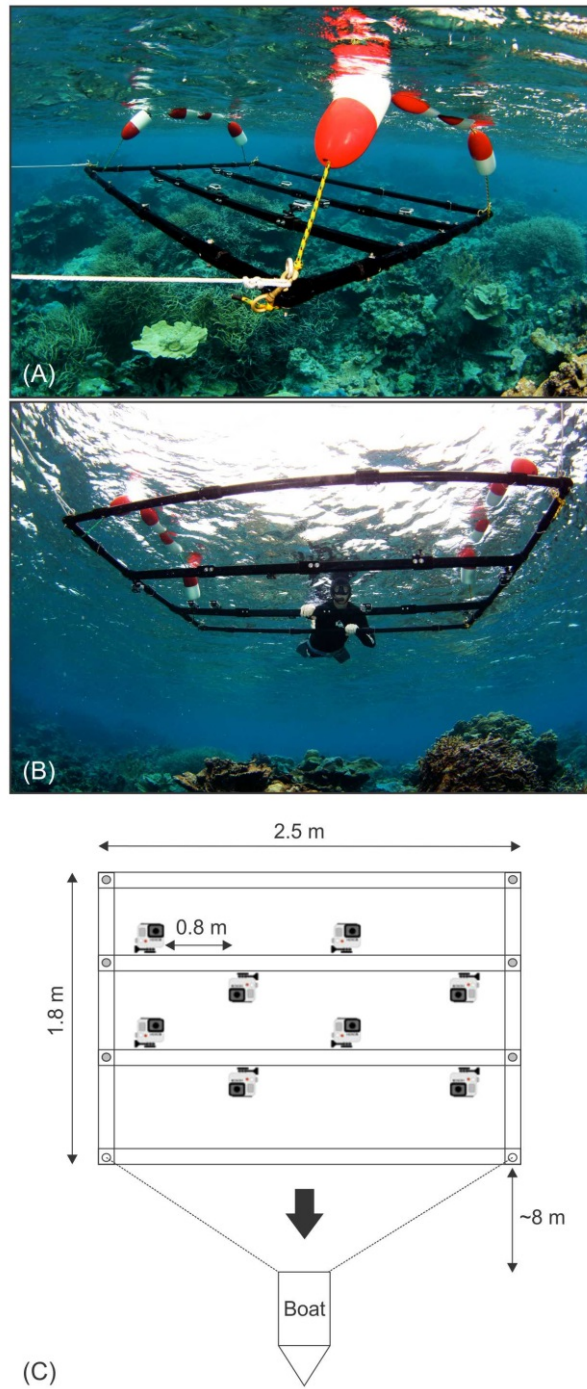
Figure 3. Our custom towed-camera system (TCS) used to capture landscape-scale imagery on Palmyra's shallow western reef terrace. A) the TCS in semi-autonomous mode being dragged by a boat, B) the TCS guided by a snorkeler in high-relief areas of the terrace, and C) GoPro© camera array set-up on the TCS.

Results to date

Qualitative observations from the large-scale TCS surveys

During TCS surveys in both 2013 and 2014 we documented cases of "*pockets of resistance*" within the *Rhodactis* phase shift landscape (up to within ~400 m of the original shipwreck location). These healthy reef patches were generally in the order of 10 m in diamater and often cicular in shape. Corals dominating these communities were predominantly *Porites rus* and *Fungia* spp., although some harbored diverse communities of *Pocillopora*, *Acropora*, and *Montipora* spp. (Fig. 4). The wreck scar appears to be clear of *Rhodactis*, potentially due to the unconsolidated nature of the substrate. The reefs directly north of the wreck scar appear healthier than in a NW direction where *Rhodactis* dominates. Ultimately the goal will be to map the location of these pockets in relation to the broader *Rhodactis* landscape and monitor their fate.
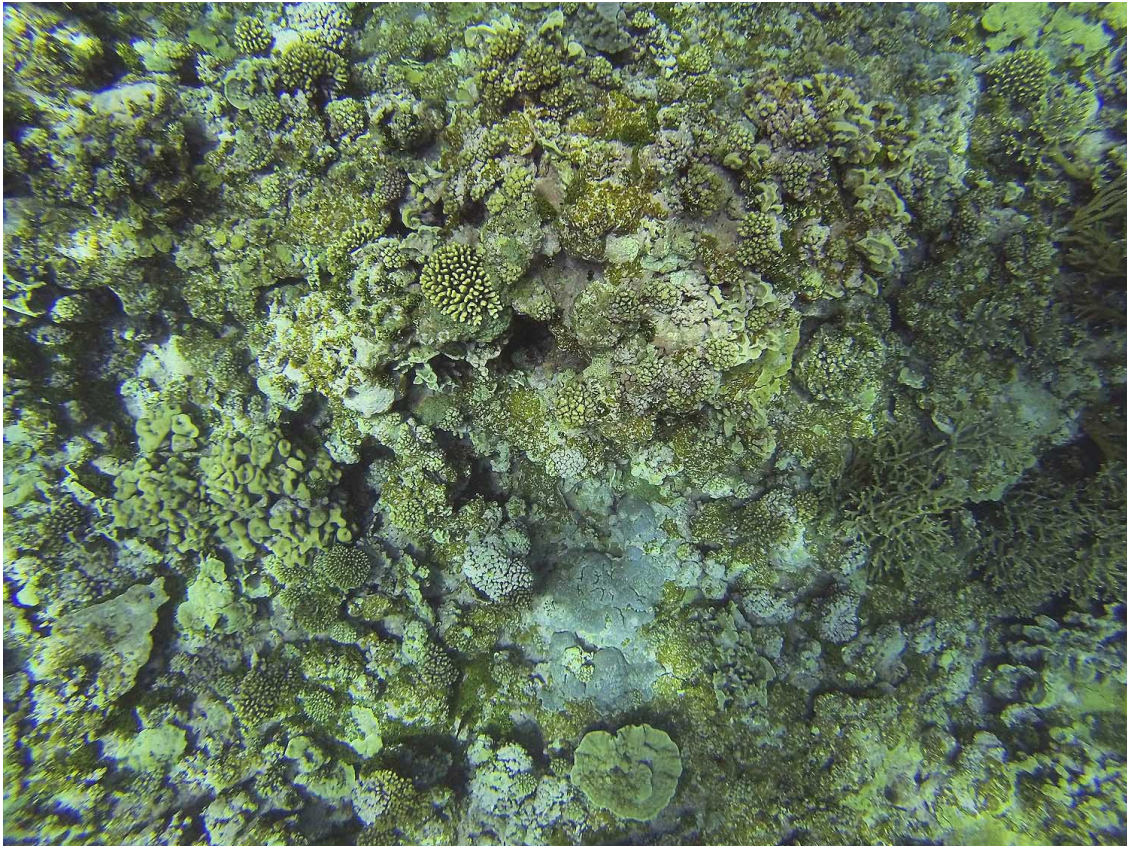

Figure 4. Frame-grab (~5 m^2) from the TCS documenting "*pockets of resistance*" within the *Rhodactis* phase shift landscape on Palmyra's shallow reef terrace. Here *Pocillopora*, *Acropora*, and *Montipora* corals appear competitively dominant and the areas are currently free of *Rhodactis*.

High-resolution Monitoring Plot

The high-resolution dual-SLR imagery has been successfully stitched together to form a sptially continuous monitoring plot (200 m^2) for three consecutive survey years (Fig. 5). From this we have seen a qualitative thinning of *Rhodactis* in some parts, but also the continued spread of *Rhodactis* and the loss of live coral cover in other parts of the plot. Quantitative spatial analyses are now required.

TCS Monitoring plot

We have encountered several technical challenges that were not fully anticipated at the onset of this project. The largest hurdle has been the data volume generated from the TCS surveys. Surveys to date have generated approximately 12 TB of high-resolution digital video data. Each survey plot (100 x 100 m) generates approximately 170,000 frame grabs that require stitching; image matching is therefore hugely computationally intensive, presenting two full orders of magnitude larger data volume than we have attacked in the past. Our collaborators at the University of Miami are working hard to solve these technical challenges associated with the automated image recognition software and are making progress on forming individual 100 x 100 m plots (formed by processing in 50 x 50 m portions) that will later be manually aligned to form the larger 35,000 m^2 monitoring plot area. The projected timeline for this is to have the first 100 x 100 m plot formed and availble to USFWS by the end of April 2015. From there, we estimate it will take approximately 3 weeks of computer runtime for each additional 50 x 50 m section of each 100 x 100 m plot to be formed and made available to USFWS (there are a total of 6 sections each taking 4 weeks to process, so 24 weeks in total – note this is for one survey year). We are currently focusing efforts on the 2014 surveys as these provided far better quality images. Because of these large computationally-intensive efforts we have decided not to collect additional field data in 2015 and instead use the funds to supplement these time-intensive efforts. The next survey season will be July 2016 and will require additional funding to complete the field surveys (~$30k) and additional funding to pre-process and stitch the imagery (~$10k) (please see the *Projected Project Timeline* chart at the end of this document for details).
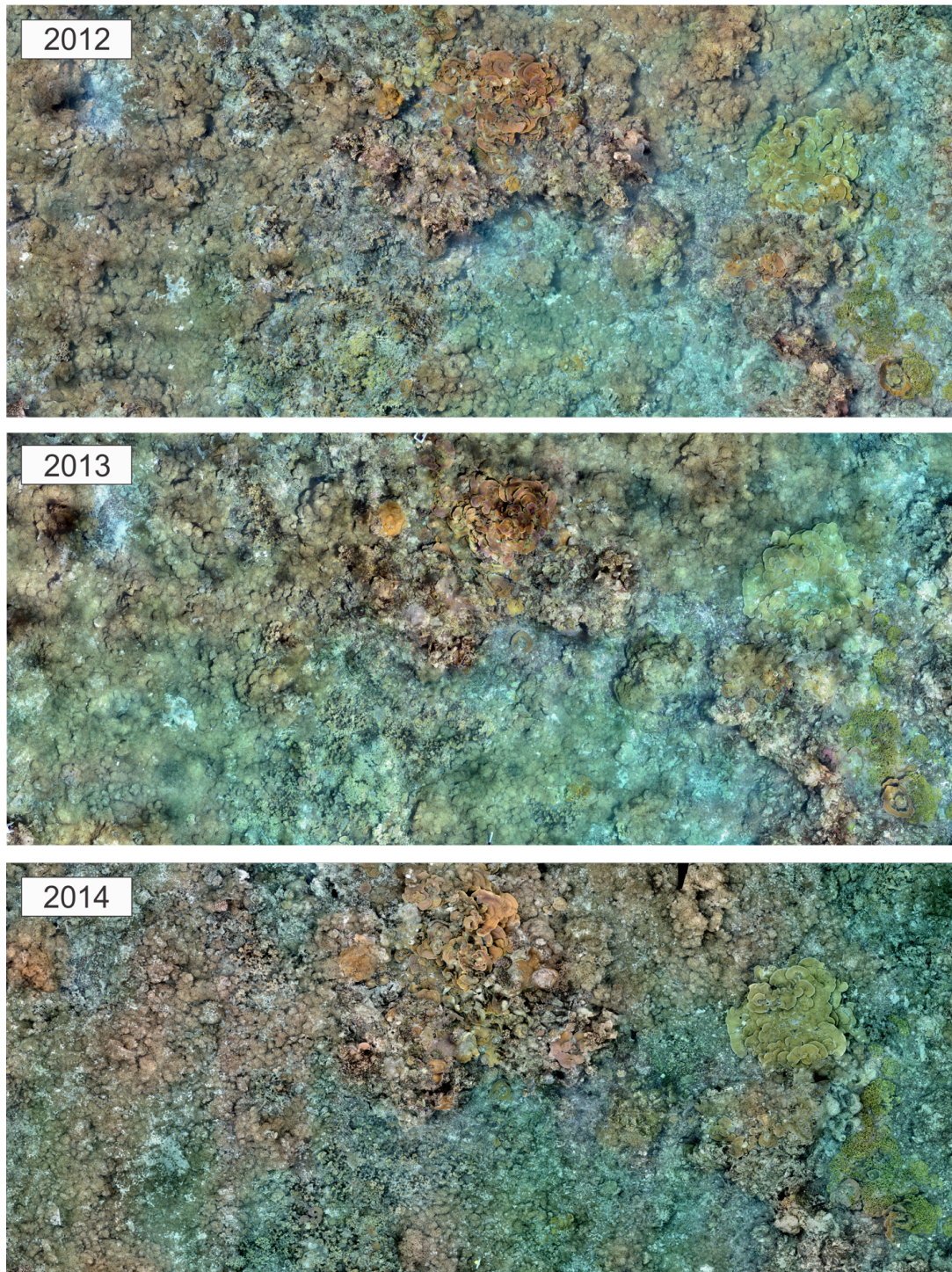
Figure 5. Timeseries of a section (~150 m^2) from our high-resolution plot embedded within our larger TCS survey plot.

Currently Available Products for USFWS

*High-resolution Imagery – included electronically with this progress report*

We have included a GeoTIFF files of the high-resolution monitoring plot (200 m^2) for 2012. This file is embedded with GPS meta-data to allow USFWS to upload to interactive mapping software (e.g. ArcGIS, Google Earth) and display the image in real space. We recommend USFWS approaches their computing and outreach departments to serve this imagery online. If this is something you find useful please let us know and we can supply the other survey years in the same format.

Outreach Products – included electronically with this progress report

In order to allow USFWS to promote the Palmyra *Rhodactis* Monitoring Project (PRMP), we have prepared printable outreach posters of the high-resolution monitoring plot (200 m^2) for all three time points captured thus far (2012, 2013, 2014). These include contact information for the project and can be sent to interested parties as PDF files. We recommend USFWS approaches their computing and outreach departments to serve this documentation online.

Future directions and opportunities

An obvious challenge is to convert the large digital monitoring plots into usable biological data that can be subjected to spatial statistics in order to learn about the spatial patterning associated with the decline or continued increase of the *Rhodactis* landscape. Forest ecologists have gained huge insights from such approaches. However, at present we are limited to the labor intensive approach of hand digitizing the imagery. Essentially this involves a person drawing around individual corals and patches of *Rhodactis* in order to then export these as individual GIS layers that can then be subjected to statistical routines. To digitize a 100 m^2 takes aproximately 3 person weeks, meaning data from our 2014 TCS survey year would take ~10 person years to fully digitize. Obviously this is not feasible (or practical). To date we have not been funded by USFWS to persue biological data processing of the imagery, but we have self-funded trial runs using the high-resolution monitoring plot (Fig. 6). These analyses are generating usable training data for machine-learning automated image recognition algorithms (bagging decision trees). In collaboration with colleagues at University of North Carolina Wilmington we have been persuing this as a means to speed up the biological post-processing of the large TCS monitoring plot. By digitizing *Rhodactis* within the high-resolution monitoring plot, the algorithms will learn the pixel intensities associated with *Rhodactis* allowing us to apply the same techniques to automatically map the larger (100 x 100 m) TCS monitoring plots. This is an exciting field of research, but requires future funding to allow dedicated time and effort toward the PRMP. We propose that we team-up with USFWS to approach potential funders or donors to accomplish this goal and create not only the largest *in situ* coral reef monitoring plots in the world, but also extract the largest high-resolution continuous biological data in existence from a coral reef.
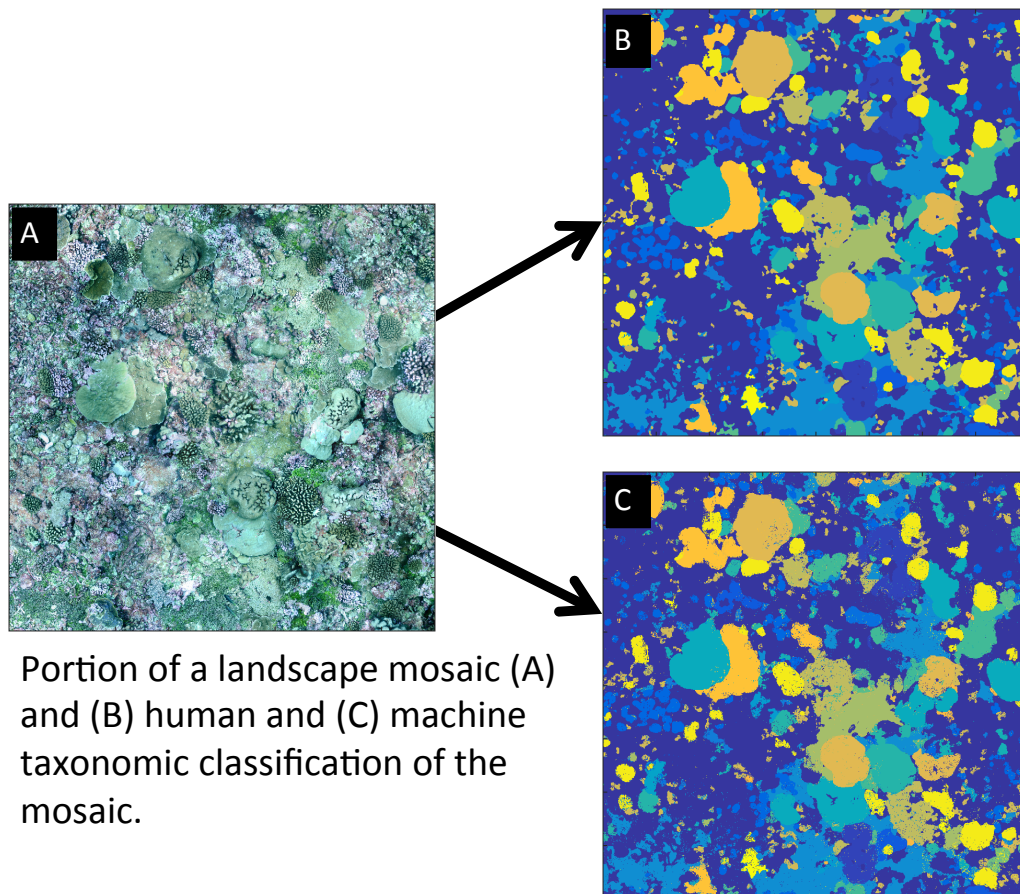
Portion of a landscape mosaic (A) and (B) human and (C) machine taxonomic classification of the mosaic.
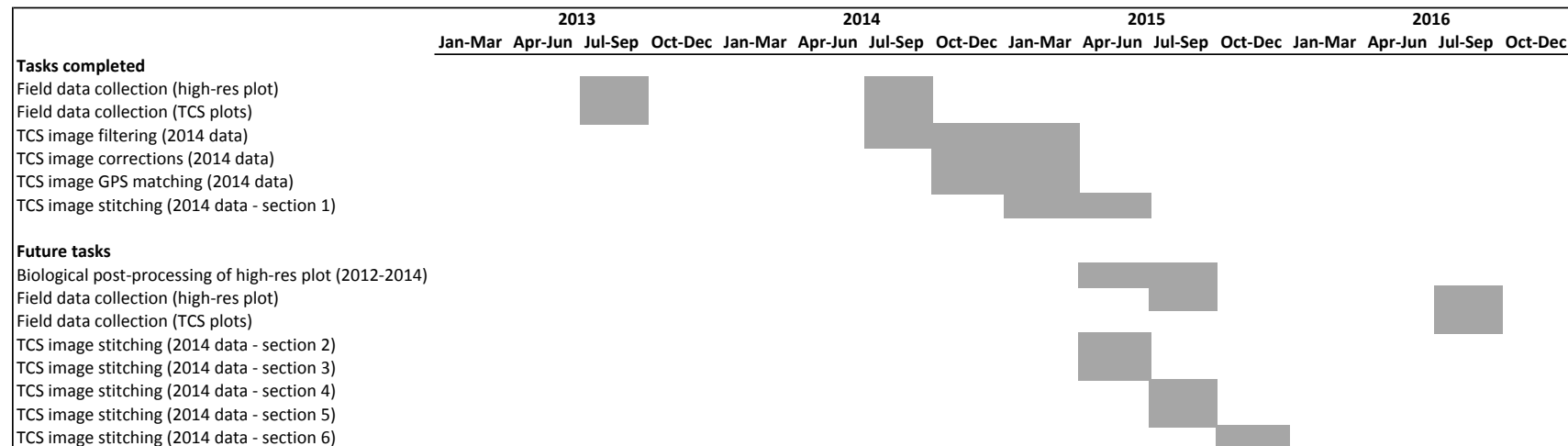
Figure 6. Machine-learning image recognition of coral reef benthic organisms. The human classification layers are used as training data, teaching the algorithms to detect organism boarders and discriminate between biological layers to a genus taxonomic resolution. At present our algorithms at reaching 93% accuracy with the human-expert layers.

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Projected Project Timeline

In the immediate future we plan to use the 2015 funds to extract biological data from the high-resolution mointoring plot. The 200 m² plot (Fig. 5) will be hand-digitized to create GIS layers for live coral cover (by genus) and *Rhodactis* cover. Once all three time points are done we will subject these layers to spatial statistics to formally test for changes in relative cover over time.

	2013				2014				2015				2016			
	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Tasks completed																
Field data collection (high-res plot)			█													
Field data collection (TCS plots)					█											
TCS image filtering (2014 data)						█										
TCS image corrections (2014 data)						█	█									
TCS image GPS matching (2014 data)							█									
TCS image stitching (2014 data - section 1)								█								
Future tasks																
Biological post-processing of high-res plot (2012-2014)										█	█					
Field data collection (high-res plot)											█					
Field data collection (TCS plots)															█	
TCS image stitching (2014 data - section 2)										█						
TCS image stitching (2014 data - section 3)										█	█					
TCS image stitching (2014 data - section 4)											█					
TCS image stitching (2014 data - section 5)											█	█				
TCS image stitching (2014 data - section 6)												█				

Note that the field data collection for the high-res monitoring plot also took place in September 2012.
Also note that imagery collected in 2016 will require further funds in order to process the imagery and stitch the imagery together.